On the contribution of quiet Sun magnetism to solar irradiance variations

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HighAltitudeObservatory

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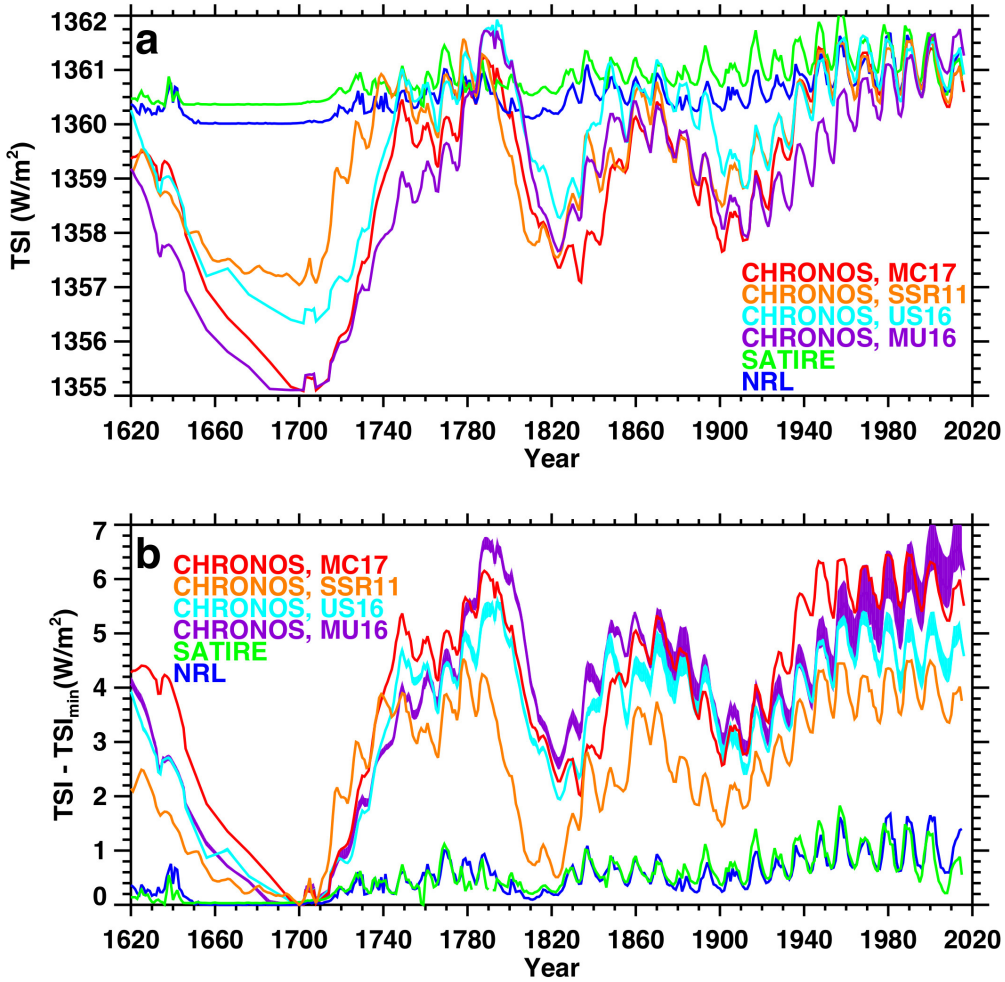
Motivation



From Egorova et al.2018

- Wide range of Grand Minimum TSI estimates:
  - Comparable to current Min (e.g. Schrijver et al. 2011)
  - 0.4% (6 W) down (Foukal et al. 2011, Shapiro et al. 2011, Egorova et al. 2018)
- Potential quiet Sun contributions?
  - How much does the QS magnetic field strength vary?
  - What is the TSI/SSI sensitivity to QS field?

Potential contribution from Quiet Sun variability?

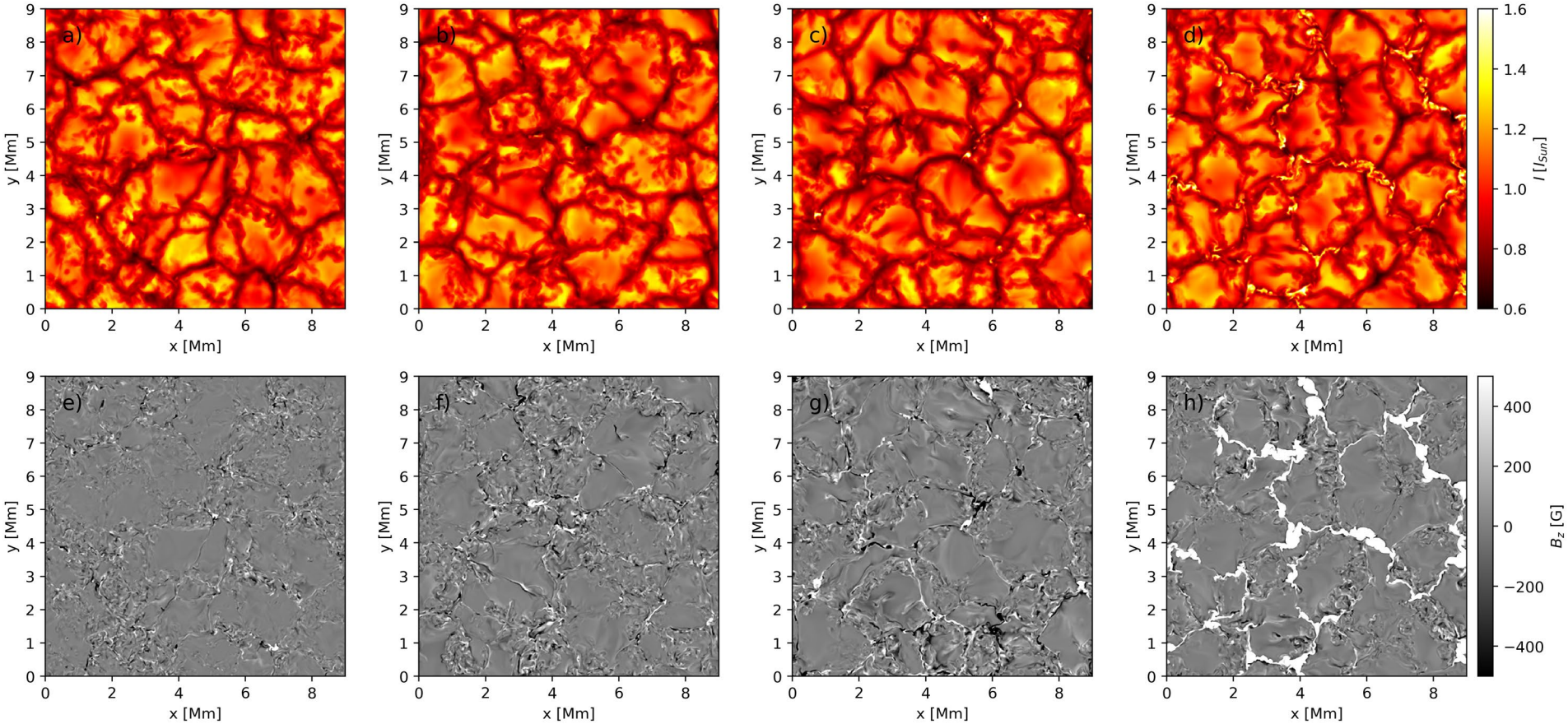
- How much does the QS vary over time?
  - Current observations based on Zeeman diagnostics suggest that there is no variability with the regular solar cycle (e.g. Buehler et al. 2013), but other works (Meunier 2018), found a 25% variation with the solar cycle
  - Whether this also holds for long-term variability is uncertain and can't be easily answered
- What are the physical bounds on the potential contribution from QS variability?
  - Use radiation MHD models to compute QS spectral solar irradiance
  - Vary the strength of the QS field and determine the SSI response
  - Explore the impact of hypothetical SSI changes on whole atmosphere climate models (see Hanli Liu's talk tomorrow)

Quiet sun models

SSD Run 6x6x3 Mm domain
@ 4km grid spacing

- Small-Scale dynamo setup
  - Mixed polarity field (no vertical netflux) maintained by turbulent dynamo
  - Open bottom boundary condition
- Saturation field strength depends on bottom boundary
  - Parameterizes coupling with deep CZ
  - Exploit this dependence to create “QS” of different strength
- Entropy of inflowing plasma fixed at bottom boundary
  - No deep seated changes of the thermal structure in CZ

QS models considered



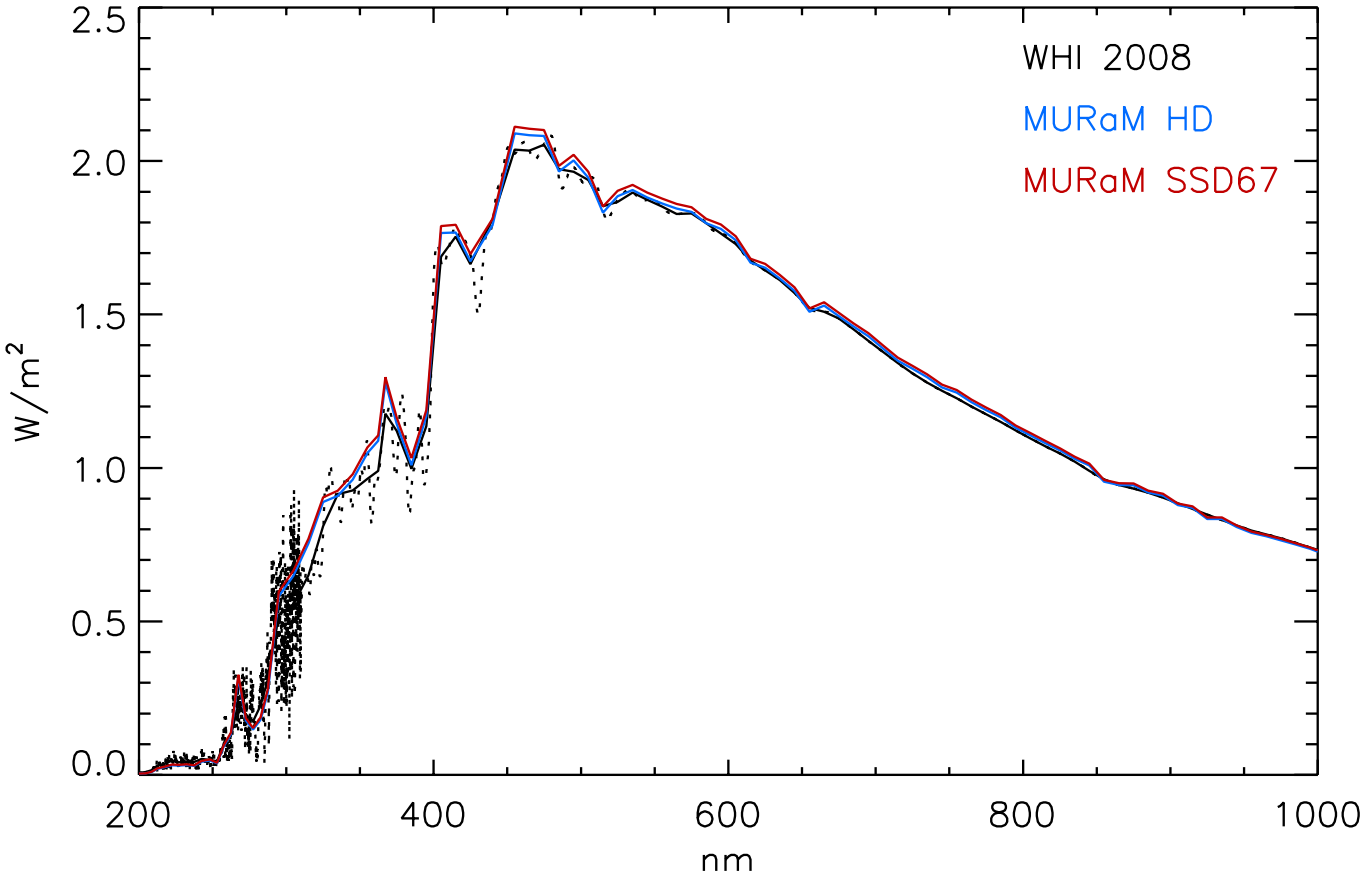
QS Weak ~46G | QS ~69G | QS Strong ~87G | 100G Network

Zeeman and Hanle measurements (e.g. Danilovic et al. 2016, del Pino Alemán et al. 2018) suggest a QS field strength (<|B_Z|> @ tau=1) of 60 – 80 G

SSI Computation

- Compute "SSI on the fly"
  - Perform diagnostic RT every 50-100 time steps for a few 100 wavelength intervals
  - No need to store and postprocess large amounts of data, only 2x cost in computing time
- Only consider (translation invariant) QS
  - No need to worry about how magnetic features are distributed on solar surface
  - Outgoing energy flux of simulation domain can be directly used to compute SSI variations
- Opacity Source
  - Castelli & Kurucz (2003) ODFs with 2 km/s microturbulence

Comparison modelled SSI to observed

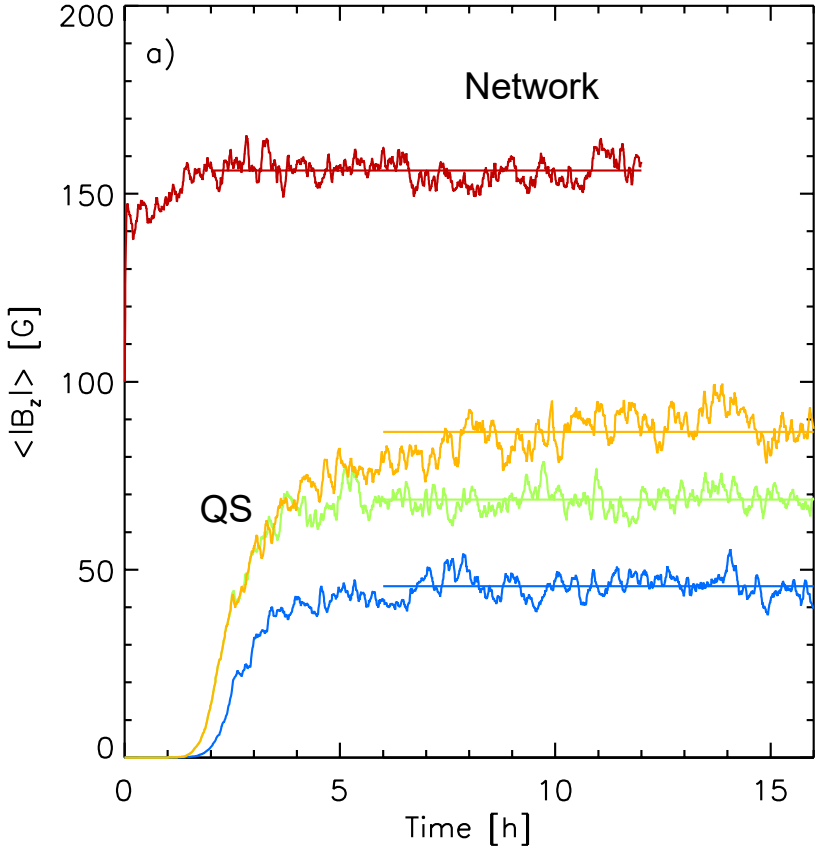


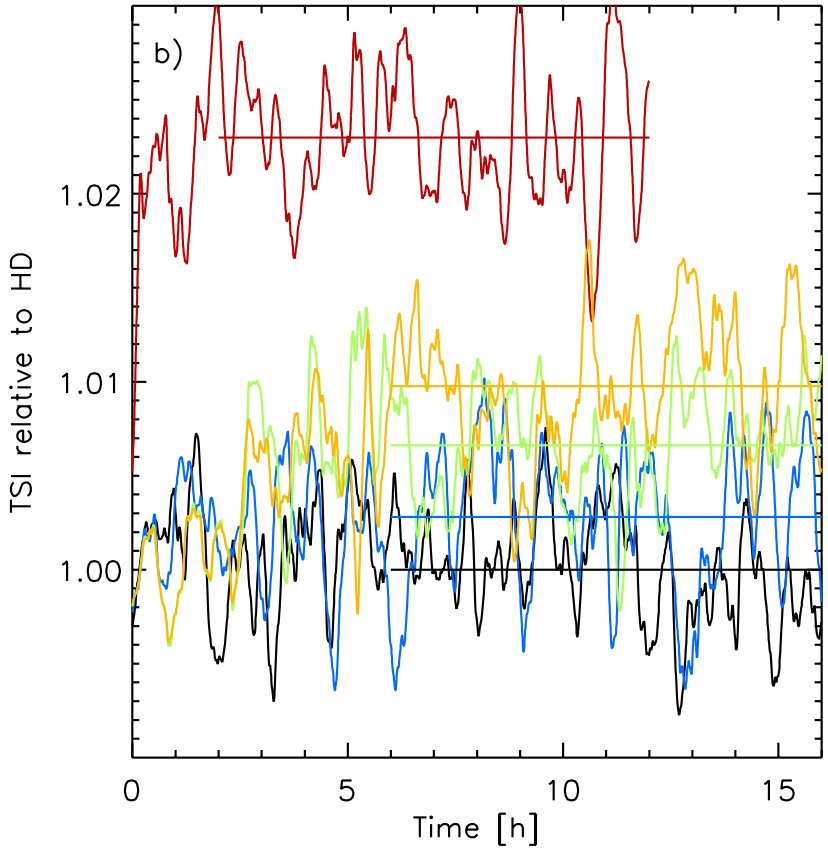
WHI 2008 spectrum (dotted) and binned to simulation (solid)

Simulated "current Quiet Sun"

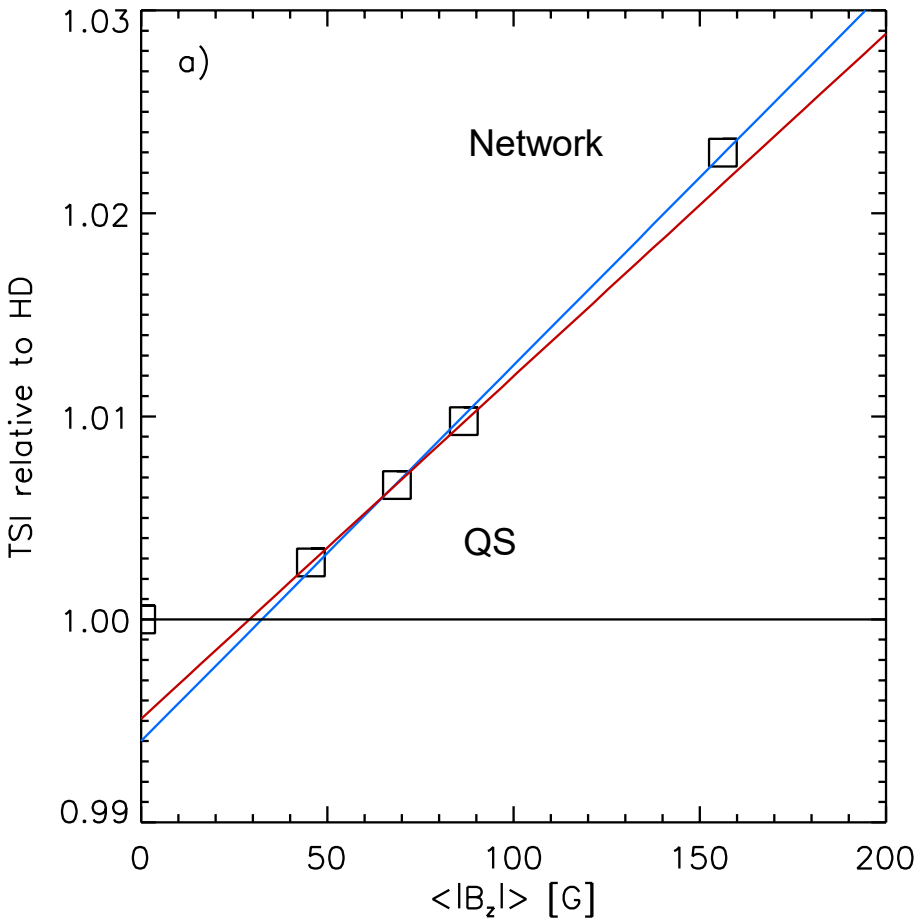
Simulated "HD Sun"

Simulation runs – TSI (smoothed)



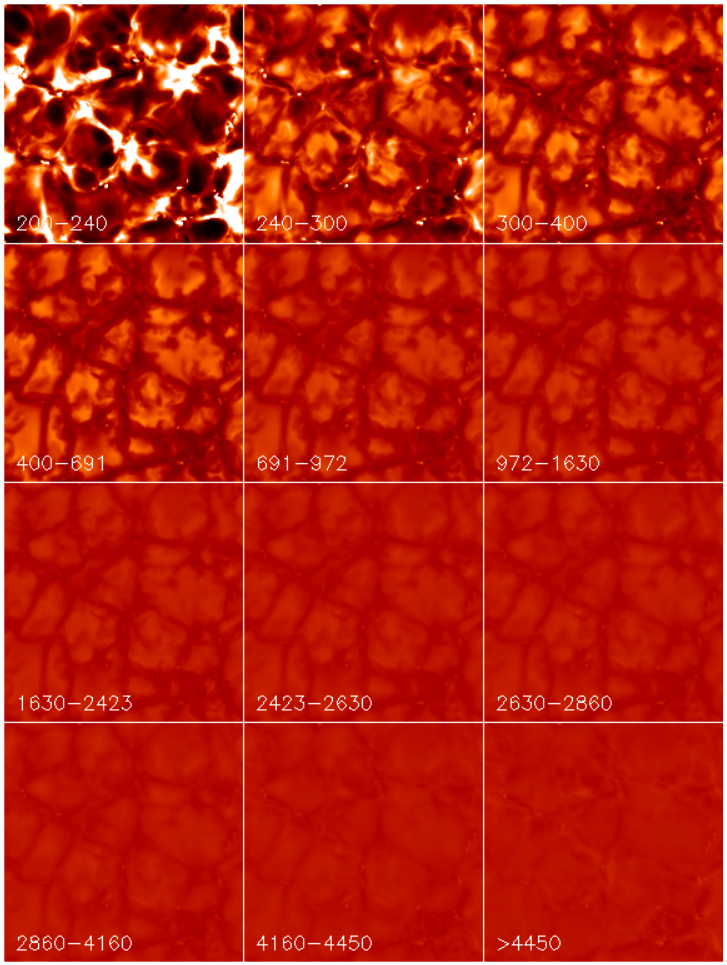


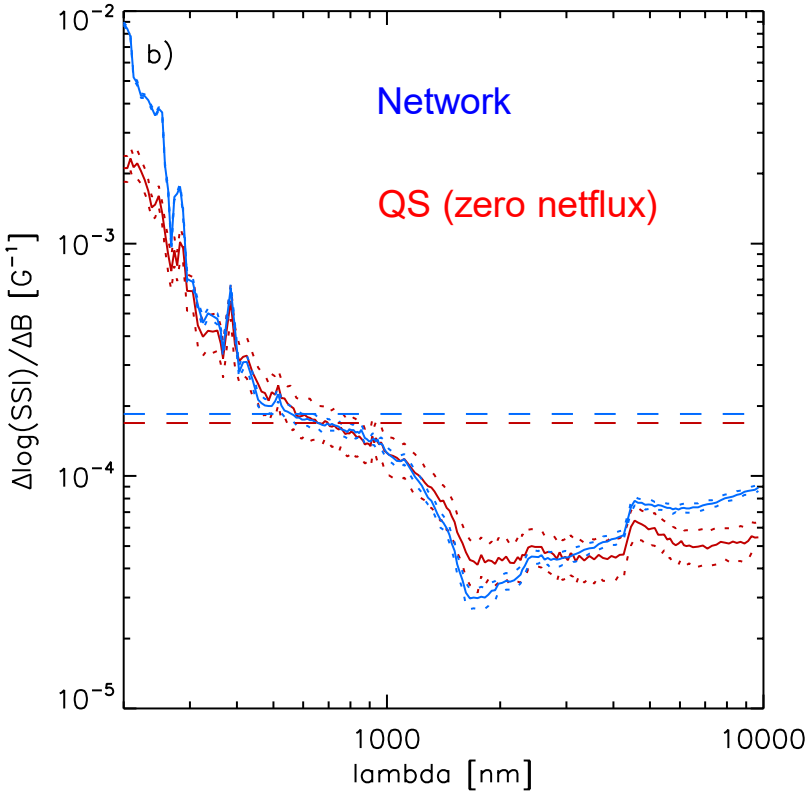
TSI sensitivity of quiet Sun



- QS and (weak) network models show similar overall trend:
  - ~0.17% per 10G of unsigned flux density at tau=1
  - Net flux imbalance has secondary effect
- HD TSI level is reached for ~30G unsigned flux
  - Below that threshold field is too weak to affect TSI
  - kG flux concentrations do only form for $<|B_Z|> > 30G$

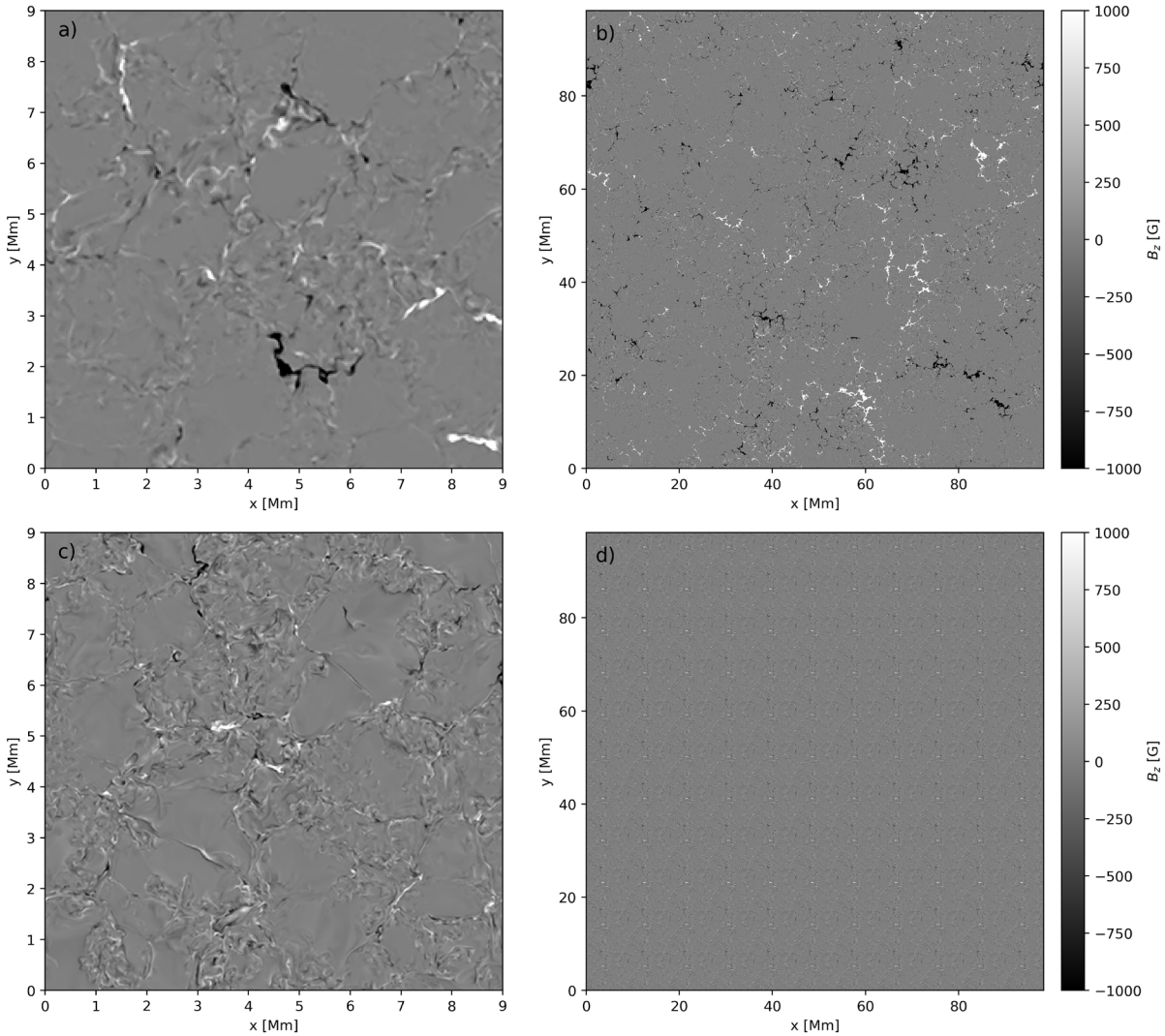
SSI sensitivity to QS field changes





See talk by H. Liu on Thursday: WACCM-X response to reduced QS driving

Is network a part of quiet Sun?



9x9 Mm

98x98 Mm

Top:

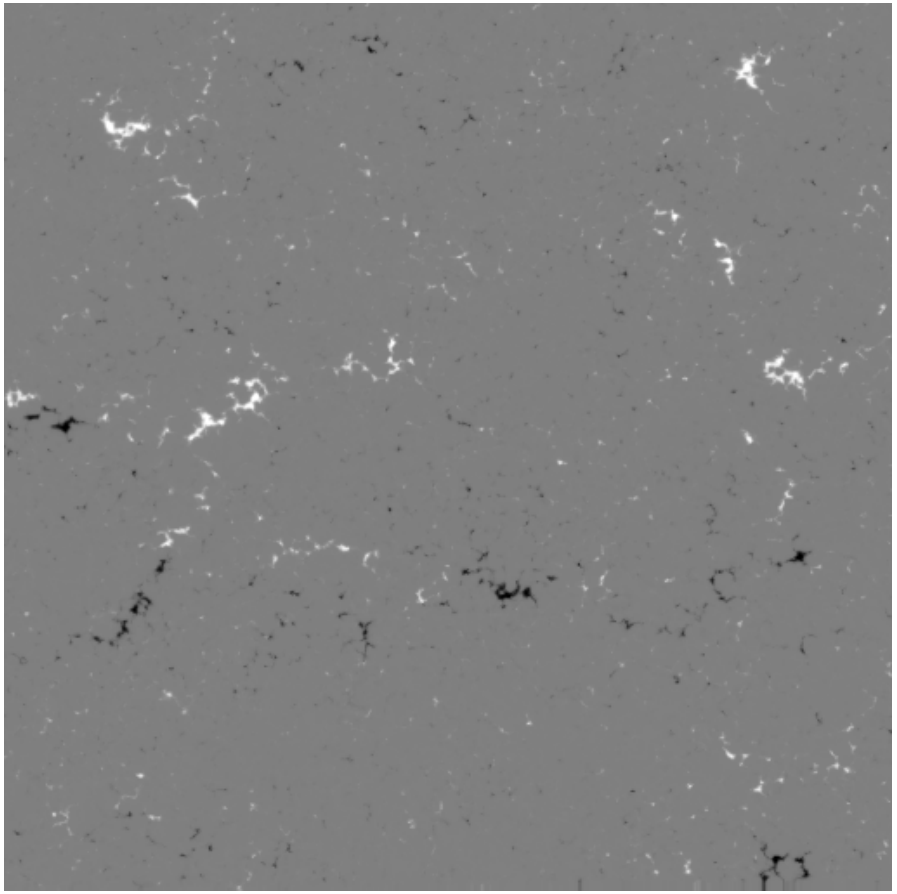
SSD simulation in 20 Mm deep domain

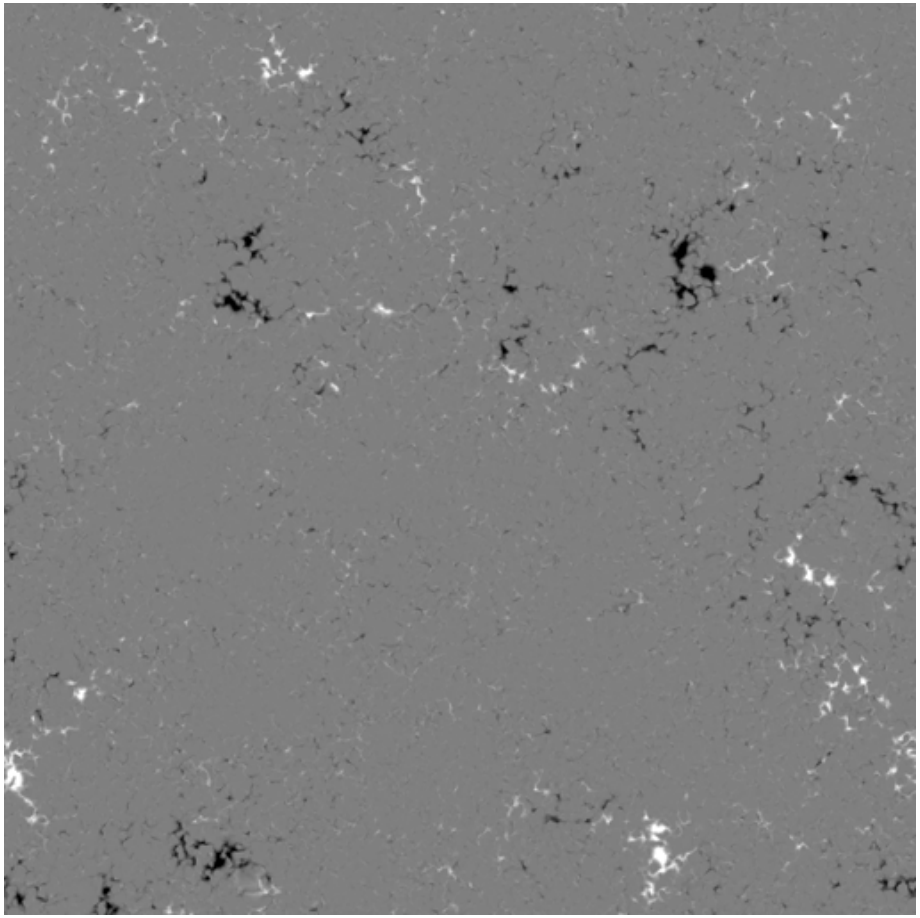
Bottom:

SSD simulation in 2Mm deep domain

(Mixed polarity) Network arises naturally from a highly stratified SSD

Quiz: Which map is an observation/simulation?





Conclusions

- QS TSI sensitivity of about **0.17% per 10G** change of unsigned QS flux at tau=1
  - 10% QS variation (7G) would cause TSI change comparable to observed Min to Max variation
  - QS cannot change significantly during normal cycle, at best a few % assuming that most observed changes can be attributed to active region (sunspots + faculae)
  - Indirect constraints of QS variability through TSI provide currently more stringent constraints than direct field measurements
  - A 25% field strength variation as found by Meunier (2018) would lead to a 0.3% TSI variation that can be ruled out during the regular cycle, but a 30 - 50% long-term variation could cause 0.4% (6 W) variations

- The absence of QS variation during the normal cycle strongly suggests that the origin of the QS field is independent from the large-scale field, i.e. a small-scale dynamo
  - SSD maintains also a mixed polarity network
  - Long-term variations are highly unlikely, as they would require substantial changes in the turbulent properties of the convection zone

Announcement: HAO Director position open

NCAR has an opening for an Associate Director/HAO Lab Director

https://ncar.ucar.edu/who -we/are/leadership/leadership -opps/hao -ad

Application review will start at 2/7 (soft close)